CONF-861102--29

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TITLE: A CORRELATION TECHNIQUE FOR SINGLE- AND TWO-PHASE PUMP DATA

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SUBMITTED TO: The American Nuclear Society's Winter Meeting, November 16-21, 1986, in Washington, DC.

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FORM NO 836 R4

A CORRELATION TECHNIQUE FOR SINGLE- AND TWO-PHASE PUMP DATA

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INTRODUCTION

A generalization of the single-phase head equation,

$$H = AN^2 + BNQ + CQ^2 \quad , \tag{1}$$

provides the basis for a new single- and two-phase pump data correlation described in this paper. In this equation, H, N, and Q are pump head, speed, and capacity, respectively.

This equation is simply a transformation of a real pump head-capacity equation obtained by subtracting hydraulic losses (due to friction, diffusion, and separation) from the ideal Euler head.[1]

In single phase, A, B, and C are coefficients depending on pump geometry and design. The generalization of Eq. (1) is to allow these coefficients also to be functions of void fraction, α_F, during two-phase operation.

In terms of normalized head and non-dimensional homologous parameters, this generalization of Eq. (1) becomes

$$h \equiv H/H_R = A(\alpha_F)\,\alpha_N^2 + B(\alpha_F)\,\alpha_N\nu + C(\alpha_F)\nu^2 \quad , \tag{2}$$

where $\nu \equiv Q/Q_R$, $\alpha_N \equiv N/N_R$, and quantities with subscript R are evaluated at rated conditions.

Whereas previous correlations factor the homologous dependence from the void dependence, the present method does not impose this restriction. For example, the Babcock and Wilcox air/water correlation takes the form

$$(C)_2 = (C)_1 \, F(\alpha_F) \quad , \qquad (3)$$

in which the homologous function, $(C)_1$, is factored from the void function, $F(\alpha_F) = 1 - M(\alpha_F)$. $M(\alpha_F)$ is the void dependent degradation factor.

Likewise, RELAP4 employs

$$M(\alpha_F) = \frac{\Delta H_1 - \Delta H}{\Delta H_1 - \Delta H_2} \quad , \qquad (4)$$

in which, again, homologous dependence is separated from void dependence.

In contrast, Eq. (2) does not imply that the void dependent factors in $A(\alpha_F)$, $B(\alpha_F)$, $C(\alpha_F)$ are equal and hence factorable from the homologous dependence. If they were, however, then Eq. (2) could be written like either Eqs. (3) or (4).

APPLICATION OF CORRELATION

For simplicity in the following material, each set of two-phase coefficients, A, B, C, will be quadratic functions of void dependence of the form

$$a\alpha_F^2 + b\alpha_F + c \quad , \qquad (5)$$

with numerical constants a, b, c. In general, the set of coefficients can be any degree polynomial function of α_F. The degree plus one will equal the number of two-phase head equations, e.g., Eq. (5) implies three head equations at α_F = 0.2, 0.4, 0.8.

Correlation equations obtained from Eq. (2) will be determined and compared with both the CE 1/5 scale steam/water[2] and B+W 1/3 scale air/water[3] correlations, respectively. For each pump, four head correlation equations will be produced: one single phase (α_F = 0.0, 1.0), for which the set of coefficients are constants in α_F; and three, two-phase (α_F = 0.2, 0.4, and 0.8), for which the set of coefficients are quadratics in α_F. The head correlation equations will be fit to pump data data at three normalized-flow to normalized-speed ratios, α/α_N = 0.5, 1.0, 2.0. For each pump, these four equations can be summarized by two equations, one for single-phase and the other for two-phase.

As an example, consider the following table of data points and subsequent h's from Eq. (2) for the CE 1/5-scale pump:

TABLE I

CE DATA AND QUADRATIC HEAD EQUATIONS

	HAN		HVN	h [from Equation (2)]
α_F \ ν/α_N	0.5	1.0	2.0	
0.2	1.08	0.75	-0.44	$0.79\ \alpha_N^2 + 1.19\ \alpha_N\nu - 1.23\nu^2$
0.4	0.75	0.35	-0.50	$0.63\ \alpha_N^2 + 0.75\ \alpha_N\nu - 1.03\nu^2$
0.8	0.40	0.15	-0.38	$0.31\ \alpha_N^2 + 0.52\ \alpha_N\nu - 0.68\nu^2$
0.0, 1.0	1.17	0.90	-0.24	$1.00\ \alpha_N^2 + 0.77\ \alpha_N\nu - 0.87\nu^2$

It is helpful to use

$$\text{HAN} \equiv h/\alpha_N^2 = A(\alpha_F) + B(\alpha_F)\ \nu/\alpha_N + C(\alpha_F)\ [\nu/\alpha_N]^2,\ \nu/\alpha_N \leq 1.0$$

$$\text{HVN} \equiv h/\nu^2 = A\ (\alpha_F)\ [\alpha_N/\nu]^2 + B(\alpha_F)\ [\alpha_N/\nu] + C(\alpha_F),\ \nu/\alpha_N \geq 1.0$$

in determining each h in Table I.

Using Eq. (5) to find the void dependent quadratics A, B, C at $\alpha_F = 0.2$, 0.4, 0.8, allows condensation of the first three h equations in the above table into one, two-phase head equation.

In summary, the single and two-phase head correlation equations for CE are:

$$h = 1.00\ \alpha_N^2 + 0.77\nu\alpha_N - 0.87\nu^2 \text{ for } \alpha_F = 0.0,\ 1.0 \qquad (6)$$

and

$$h = (-0.8\alpha_F + 0.95)\ \alpha_N^2 + (2.71\alpha_F^2 - 3.83\ \alpha_F + 1.85)\ \nu\alpha_N +$$

$$(-0.21\alpha_F^2 + 1.13\alpha_F - 1.45)\ \nu^2 \text{ for } 0.2 \leq \alpha_F \leq 0.8\ . \qquad (7)$$

A similar approach results in the following two equations for the B+W 1/3-scale air/water pump:

$$h = 1.09\alpha_N^2 + 0.78\alpha_N\nu - 0.87\nu^2 \ , \ \alpha_F = 0.0,\ 1.0 \tag{8}$$

and

$$h = (4.06\alpha_F^2 - 4.33\alpha_F + 0.78)\alpha_N^2 + (-2.21\alpha_F^2 + 0.94\alpha_F + 1.16)\ \alpha_N\nu + (0.67\alpha^2 + 0.35\alpha - 1.06)\nu^2 \text{ for } 0.2 \le \alpha_F \le 0.8 \quad . \tag{9}$$

Figure 1 shows solid line graphs of the CE steam/water data correlations for $0.5 \le \nu/\alpha_N \le 2$ at the five void fractions specified in Table I. These data correlations are compared with the head correlation in Eqs. (6) and (7). Recall that Eqs. (6) and (7) were determined from the data at $\nu/\alpha_N = 0.5$, 1.0, and 2.0.

Figure 2 is similar to Figure 1 with the exception of the B+W air/water correlations being compared with the head correlation Eqs. (8) and (9).

In general, the head correlation equations match their respective data correlations well. Note, in particular, that quadratic coefficients in void dependence were used in Eqs. (6), (7), (8), and (9), whereas the data correlations, which assumed separability of void and homologous dependencies, required void dependent polynomials of at least degree seven.

SUMMARY AND CONCLUSIONS

Generalizing, a quadratic single-phase homologous head equation for two phase provides a means of correlating single- and two-phase data into two quadratic homologous equations with void dependent coefficients that can be polynomial functions of degree n.

In addition to conveniently condensing large amounts of single- and two-phase data into two relatively simple algebraic equations, this new correlation also demonstrates that homologous and void fraction dependencies are, in general, not separable for two-phase pump flow.

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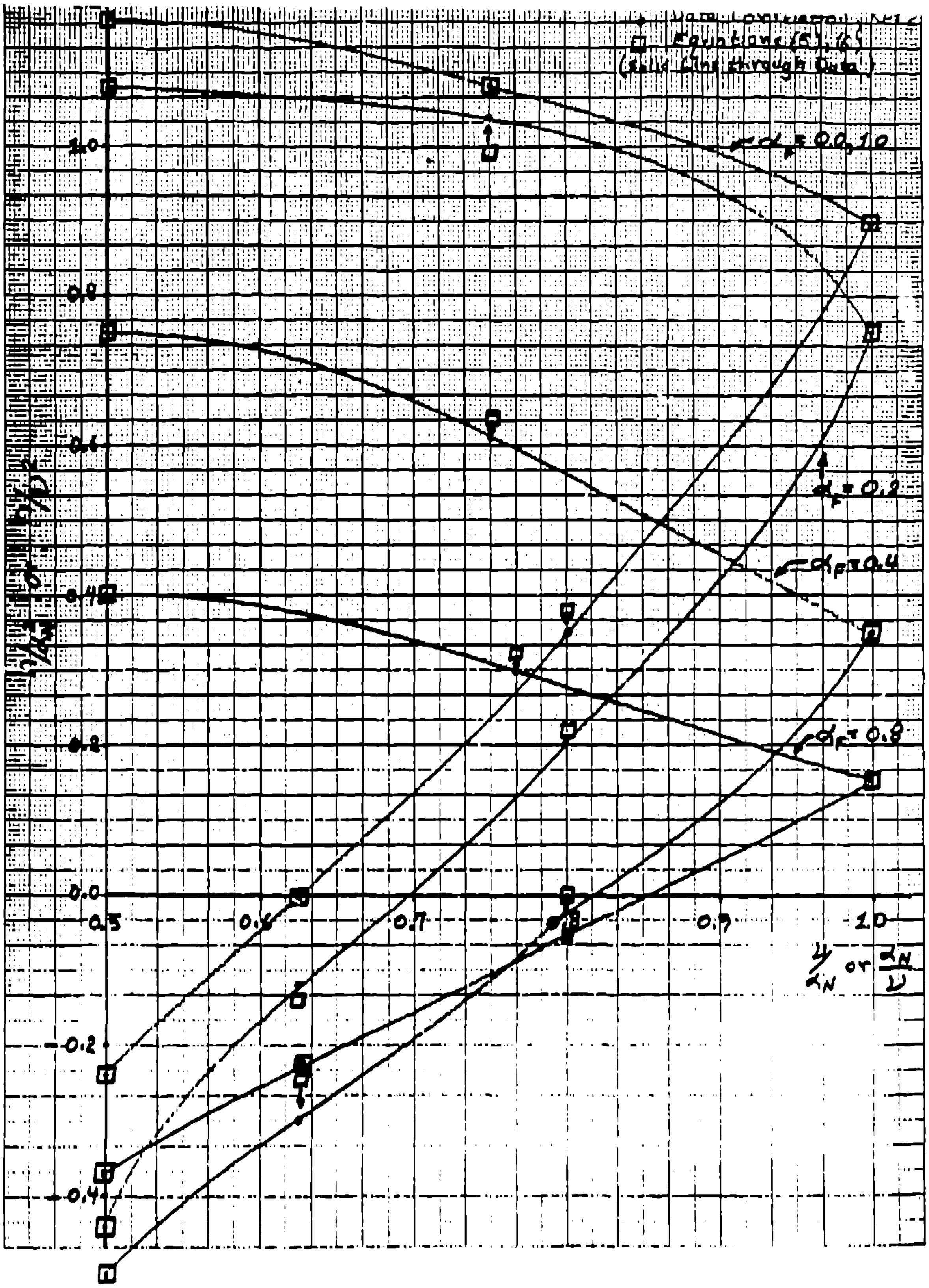

Fig. 1. CE Head Correlation Equation Compared with Data Correlation.

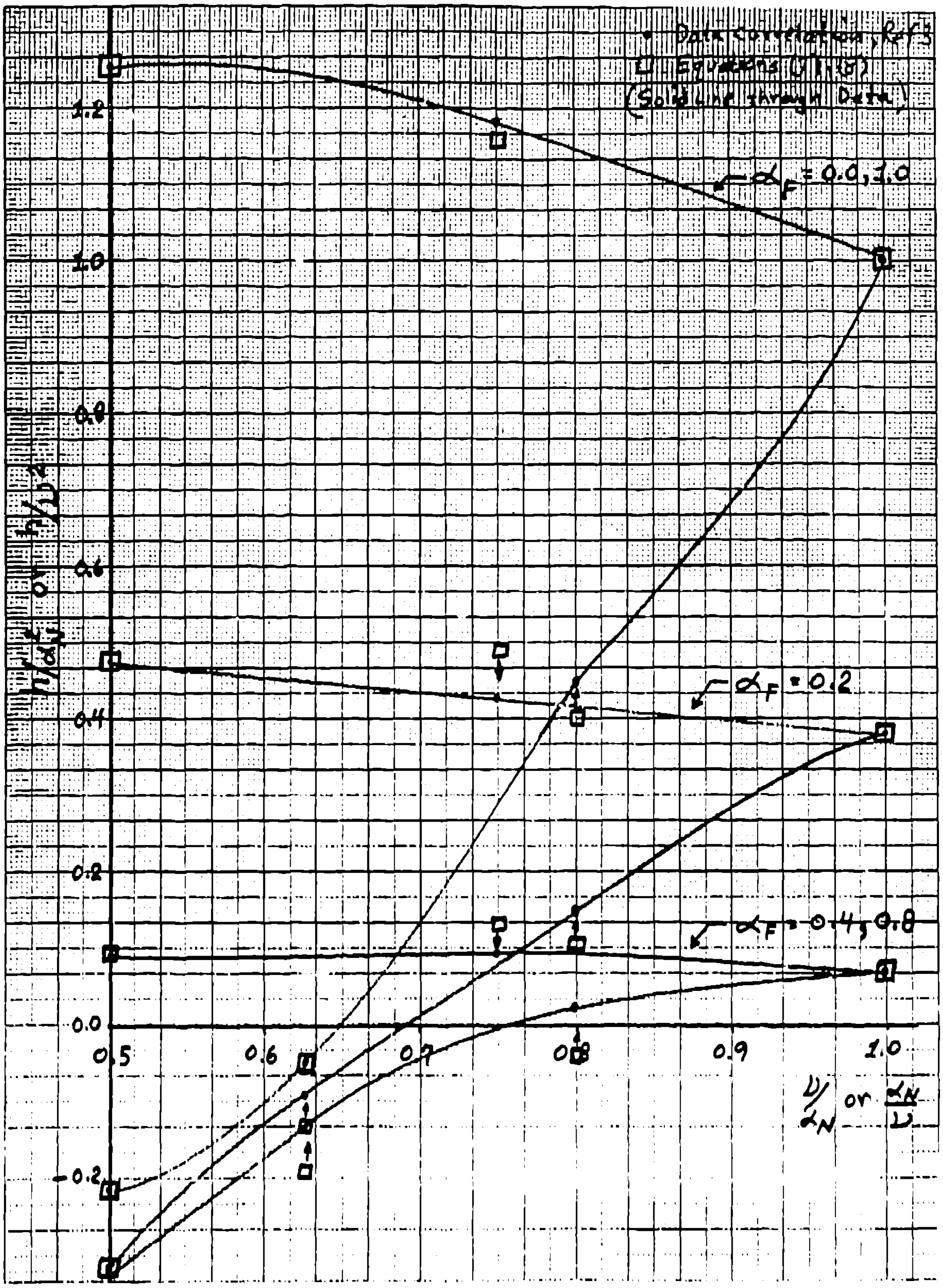

Fig. 2. B+W Head Correlation Equation Compared with Data Correlation.